

Characterization of Shear Strength Parameters for Construction Works in Ado-Ekiti Metropolis, Ekiti State, Southwestern Nigeria

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Abstract

This study presents the geotechnical characterization of shear strength parameters of soils within Ado-Ekiti metropolis, Ekiti State, Southwestern Nigeria, with a view to assess their suitability for construction works. Rapid urban development in the region has increased the demand for reliable subsurface information to ensure structural stability and prevent geotechnical failures. Field and laboratory investigations were carried out on soil samples obtained from ten (10) strategic locations, namely Adebayo, Bank Road, Abekoko, Omisanjana, Ado-Ikere Road, Basiri, Oke-ila, Ijigbo, Ado-Ilawe Road, and NTA Road. A total of fifty (50) samples were collected at a depth of approximately 1m in accordance with BS 1377 procedures. The tests conducted include Natural Moisture Content, Specific gravity, Particle size distribution, Atterberg limits, and Triaxial compression tests for the determination of shear strength parameters. The results show that the soils are predominantly lateritic in nature, with varying proportions of sand, silt, and clay fractions. The percentage of fines (<0.075 mm) ranged from approximately 13% to 78%, suggesting a wide variation in soil gradation across the study area. The liquid limit values ranged from 22% to 64%, while the plasticity index varied between 5% and 32%, indicating soils of low to high plasticity classifications under the Unified Soil Classification System (USCS), mainly within CL and SC groups. Natural Moisture Content values ranged from 13% to 38%, reflecting the influence of climatic conditions and drainage characteristics. Specific gravity values varied between 2.20 and 2.68, consistent with lateritic soils derived from basement complex rocks. Shear strength parameters obtained from triaxial tests revealed cohesion values ranging from 15.70 kN/m² to 137.90 kN/m² and angles of internal friction between 4° and 24°. The results show that soils with higher plasticity indices generally exhibit higher cohesion but lower friction angles, while soils with lower plasticity display improved frictional resistance. The findings indicate that the soils within Ado-Ekiti possess moderate to high shear strength characteristics suitable for most civil engineering applications, including shallow foundations and pavement subgrades. However, areas with high plasticity and low friction angles, particularly in Abekoko, Omisanjana, and Ado-Ilawe, may require soil stabilization and proper drainage measures to enhance performance. This study provides essential geotechnical data for design and construction practices in the region and emphasizes the importance of site-specific investigation for sustainable infrastructure development.

Keywords: Shear strength, Lateritic soils, Angle of internal friction, Soil classification, Geotechnical investigation.

1.0 Introduction

The strength and behaviour of soil is a significant factor in the performance and stability of civil infrastructure. In geotechnical engineering, soil is used to serve two major purposes: as a foundation to bear loads from structures and as a construction material for building highways, embankments, earth fills, slopes and pavement layers. Therefore, a thorough knowledge of the properties of soil engineering is crucial for safe designing of foundations, highways, other civil engineering structures and for sustainable infrastructure development [1], [2]. The geotechnical knowledge is especially critical in rapidly urbanizing cities like Ado-Ekiti where construction activities are inexorably growing, and the soil properties can so differ even within short distances in the city that it is vital to have reliable geotechnical information.

Shear strength is one of the most important engineering properties of soil as it relates to the resistance of the soil to shear failure along potential slip planes. The shear strength is often described by cohesion (c) and by the angle of internal friction (ϕ) and these are known as the Mohr–Coulomb failure criterion. The parameters are important for the design and analysis of foundations, retaining structures, embankments, pavements and slopes, and for the assessment of the bearing capacity as well as the overall stability of the ground [3], [18], [19], [23]. If not, the soil may undergo excessive settlement, bearing capacity failure, cracking, tilting, or even total failure of structures in severe cases.

Lateritic soils are the major residual soils in Southwestern Nigeria and are quite common as construction materials. Yet, the soils are quite variable in their engineering characteristics, based on their origin and formation process, and these characteristics are important in economic analyses. The engineering properties are affected by various factors such as the type of parent rock, degree of weathering, clay mineral content, fines content, moisture content of the rock, density and laterization [4], [7], [9], [10]. Adeyemi [7] showed that the engineering index

properties of residual lateritic soils are greatly influenced by parent rock. Similarly, Mesida [9] correlated the engineering properties of the lateritic soils with the geological and mineralogical properties and Olatunde et al. [4] reported that lateritic soil with different parent materials vary in their moisture holding capacity, plasticity, swelling potential, bearing capacity and shear strength.

Ado-Ekiti has experienced a lot of variations in the geotechnical properties of the lateritic soils as reported in previous geotechnical investigations conducted in the area. Even variations in natural moisture content, specific gravity, particle-size distribution, Atterberg limits, compaction characteristics, California Bearing Ratio (CBR), and engineering classification [1] have been noted. Some of the soils found within the metropolis meet the requirements for use as the base or sub-base materials; while others are more suitable for subgrade construction or earth fills, according to Osuji and Akinwamide [1]. The results of these investigations show that lateritic soils in Ado-Ekiti cannot be considered as homogeneous engineering materials. This variability is practically significant as many instances of pavement failures and deterioration in the country have been cited as a result of improper geotechnical site investigations, lack of understanding of subsurface condition and selection of improper construction materials [13], [15], [24].

Other factors which have a strong influence on the engineering behaviour of tropical residual soils are moisture content and clay mineralogy. Some important properties like plasticity, swelling potential, water absorption and shear resistance are controlled by clay minerals. Sridharan and Choudhury [11] along with Mitchell [12] reported that expansive clay minerals have a significant influence on soil strength and volumetric changes. Likewise, Bronick and Lal [14] noted that soil structure and particle aggregation are important considerations for the engineering properties of the soil. In Ado-Ekiti, these properties are especially significant as rain causes the soil to have considerable loss of strength due to the high proportion of fine particles and the resulting plastic nature of the soil, leading to pavement failure, reduction in bearing capacity, settlement and rutting.

The shear strength parameters are typically calculated from laboratory testing, like direct shear and triaxial compression tests. These methods can be reliable, but they are often costly, time-consuming and labor-intensive. Soil shear strength has thus been investigated in terms of other easily measurable soil index properties. Iyeke et al. [3] showed that certain parameters like plasticity index, specific gravity and percentage passing the No. 200 sieve could be used to predict the shear strength properties of lateritic soils. The same type of correlation between the soil index properties and the cohesion and angle of internal friction parameters has been reported by other researchers [16], [17], [21], [22]. However, predictive correlations should be used alongside rather than in place of careful laboratory analysis, especially in regions of high spatial variability of soil properties.

On this background, the current study focuses on the shear strength parameters of laterite soils for constructional works in Ado-Ekiti metropolis of Ekiti state, Southwestern, Nigeria. In particular, this study is designed to establish the soil index properties at representative sampling locations, review the soil cohesion and angle of internal friction at the representative locations, review the relationships between the shear strength parameters and engineering index properties and review the implications of the results on construction practice. The outcomes will help engineers, contractors, planners, and other interested parties to make informed decisions on the foundation design in the study area, pavement construction, and infrastructure development that will be sustainable.

2.0 Location of Study

The study was done in Ado-Ekiti metropolis which served as the administrative capital of Ekiti State in south western Nigeria. Ado-Ekiti is geographically situated within the latitudes 7°31'N – 7°49'N and longitudes 5°07'E – 5°27'E, the metropolis is in the tropical rainforest ecological zone, and has a humid tropical climate with two seasons: wet season and dry season. It has an average annual rainfall of about 1200 to 1500mm and mean temperatures are relatively high throughout the year, with an average ranging from 25°C to 32°C. The dominant climatic conditions lead to highly weathered underlying rocks and have a strong effect on soil formation, moisture properties and engineering properties of soils in the study area.

Ado-Ekiti geologically lies within the Precambrian Basement Complex, which is mainly composed of granite, gneiss and schist. These rocks are known to be long duration rocks that have been weathered to form the residual lateritic soils widely distributed throughout the study area. The soils are normally reddish-brown in colour, are generally of low to medium plasticity and strength, and have a content of iron oxides.

The topography of the area is generally flat with only slight hilly relief of 250 m to 500 m above sea level. Seasonal streams and rivers are the drainage condition of this area, and may affect the soil moisture and engineering characteristics of the area. Adebayo, Bank Road, Abekoko, Omisanjana, Ado-Ikere Road, Basiri, Okela, Ijigbo, Ado-Ilawe Road and NTA Road are study sites that represent and capture both residential and commercial areas with current construction activity.

3.0 Materials and Methods

3.1 Study Design and Sampling Strategy

A systematic field and laboratory-based approach was used to assess the shear strength characteristics of the soils in Ado-Ekiti metropolis in Ekiti State (Southwestern Nigeria). The soil sampling was representative of four areas and then detailed laboratory testing was conducted to measure both index and engineering properties.

Ten (10) sampling points were chosen in the study area namely, Adebayo, Bank Road, Abekoko, Omisanjana, Ado/Ikere Road, Basiri, Okela, Ijigbo, Ado/Ilawe Road and NTA Road. They were selected to reflect a variety of land uses such as residential, major road corridors and areas with on-going construction. The choice provided a good spatial coverage and representation of the different geological and environmental conditions of the metropolis.

Five (5) soil samples were taken at each of the sampling points, giving a total of fifty (50) soil samples for laboratory analysis. Samples were taken between approximately 1.0 and 1.5 m below the ground surface corresponding to the typical zone of influence of shallow foundation systems. When possible, disturbed and undisturbed soil samples were gathered to meet the needs of the various geotechnical laboratory tests used in the study. The map of the study area is given in Figure 1.

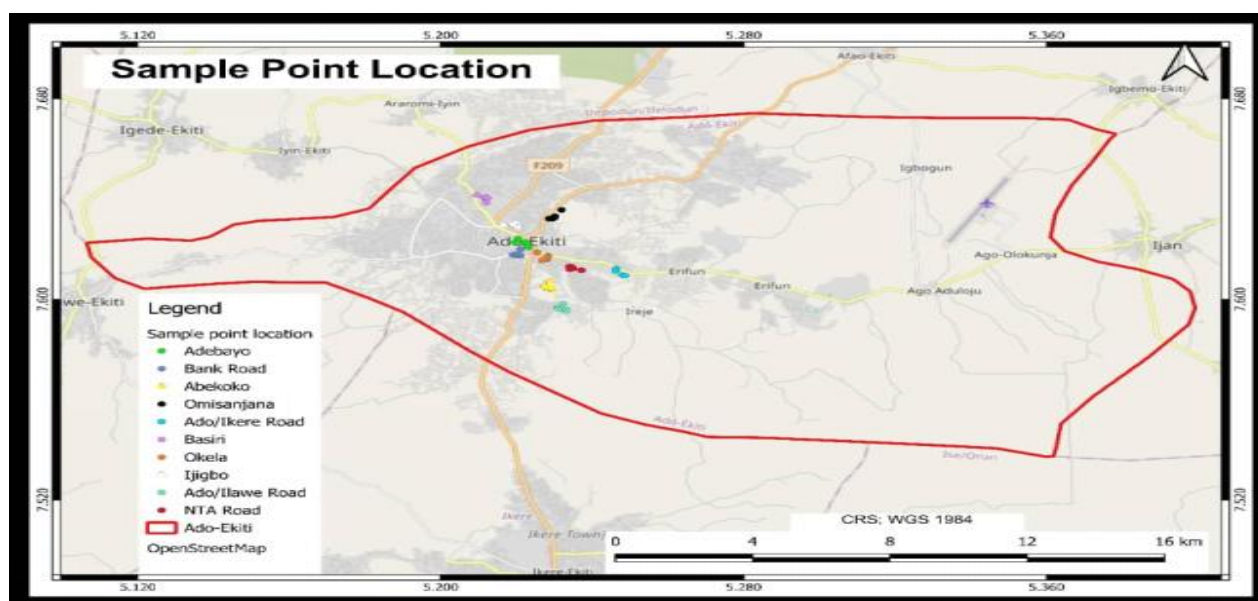


Figure 1: Map of the study area

3.2 Sample Collection and Preparation

The soil samples were made using conventional geotechnical methods. Hand augers and shovels were used to collect disturbed samples with the samples stored in airtight polyethylene bags to retain natural moisture content. Thin-walled sampling tubes were used to minimize disturbance to the soil structure to collect undisturbed samples in preparation for shear strength testing.

Samples were all properly labeled, and shipped to the geotechnical laboratory for testing purposes. Samples were prepared according to the standard procedure before testing; air-drying, removal of the organic matter, and sieving if necessary. All precautions were taken to avoid noticeably changing the natural properties of the soil when preparing it.

3.3 Laboratory Testing Procedures

All laboratory testing was carried out using the procedures outlined in British Standard BS 1377 (1990) that covers the testing of soils for civil engineering works. The laboratory programme included determination of natural moisture content, specific gravity, particle size distribution by sieve analysis, Atterberg limits and triaxial compression tests. The choice of these geotechnical tests was made to ensure that a full range of physical properties and engineering behaviour of the soils could be assessed so that they could be evaluated for suitability in construction.

3.3.1 Natural Moisture Content (NMC)

A pre-weighed aluminium moisture container was filled with ~20 g of the moist soil sample and the mass of the container and moist soil was determined. The container, after the lid was removed and placed under the container, was then placed in a drying oven at 100°C for 18 hrs to ensure complete removal of moisture. The

container was then taken out of the oven, cooled and reweighed to calculate the mass of the dry soil. Then the moisture content of the sample was determined as NMC using Equation (1).

$$NMC = \frac{\text{mass of moisture}}{\text{mass of dry soil}} \times 100 \quad (1)$$

3.3.2 Grain Size Analysis Test

The procedure involved weighing a representative sample of 500 grams of oven-dried soil. The soil sample was subsequently washed using a 0.075 mm sieve to wash away the fine soils from the sample. The sample which remained on the sieve after washing was dried in an oven for about 18 hours to dry off all the moisture. The sample was later poured into a set of sieves placed in a sequence of decreasing aperture sizes on a mechanical sieve shaker where the shaking was done for ten minutes. At the conclusion of sieving process, the soil retained on each sieve was weighed and recorded according to the specific sieve size. The grain size distribution graph was later constructed by plotting the amount of soil passed by each sieve against the size of the particles. Grain Size Analysis was determined using equation (2), whereas Percentage Passing Each Sieve was calculated using equation (3).

$$\% \text{ Retained} = \frac{\text{mass retained}}{\text{Total soil weight}} \times 100 \quad (2)$$

$$\% \text{ Passing} = 100 - \text{cumulative of } \% \text{ retained} \quad (3)$$

3.3.3 Liquid limit (LL) Test

About 200 g of oven dry soil which passed the 425 μm sieve was thoroughly mixed with water on a glass plate to obtain a uniform soil paste. The prepared sample was then covered and allowed to stand for about 24 hours to ensure complete moisture equilibration. Following the soaking process, the soil was remixed completely with spatulas to obtain the uniform consistency. The cone penetrometer was prior adjusted and calibrated before the test was started. The soil paste was carefully put into the sample cup and the first reading of the dial gauge was taken. The cone was then dropped onto the soil under its own weight for 5 seconds and a final reading was obtained. A small sample of the soil tested was removed for moisture content measurements. The rest of the soil was put back into the glass plate with a little water; the sample was remixed well and the sample cup was cleaned and refilled. The process was repeated five times to get penetration range at different moisture contents. The liquid limit of the soil was then found at moisture content which allowed a 20 mm depth of cone penetration.

3.3.4 Plastic limit (PL) Test

For the liquid limit test, the liquid content to be used was the same soil paste which had been used in the liquid limit test for the plastic limit test. A part of the sample was manually kneaded and rolled on a smooth surface until threads of about 3 mm diameter were obtained. At this diameter the soil threads started to break and soil samples were taken from the soil to determine the moisture content. The process was repeated several times to ensure uniform results to obtain the plastic limit of the sample, taken as the average moisture content of the crumbled soil threads. The plastic limit was then determined by using Equation (4).

$$PL = \frac{\text{mass of moisture}}{\text{mass of dry soil}} \times 100 \quad (4)$$

3.3.5 Plasticity Index

The plasticity index (PI) is mathematically defined as the difference between the liquid limit (LL) and the plastic limit (PL) of the soil sample. This indicates the water content range at which the soil shows plastic nature and can be moulded easily without any cracking or flowing. The plasticity index is an important parameter from an engineering point of view that is utilized to determine soil properties such as soil consistency and workability.

$$PI = LL - PL \quad (5)$$

where: LL = liquid limit and PL = plastic limit.

3.3.6 Triaxial shear test

Triaxial compression test was carried out to evaluate the shear strength properties of soil specimens in a controlled laboratory environment. The test was done in compliance with the procedure laid down in BS 1377: Part 7 (1990) for soil testing.

For each test, soil specimen was wrapped in thin rubber membrane to isolate the specimen from the cell fluid and then placed in the triaxial cell. The cell was then filled with fluid to apply equal confinement (σ_3) on all sides of the specimen. Axial load was then applied on the specimen using loading piston to induce deviator stress ($\sigma_1 - \sigma_3$) on the specimen resulting in its deformation up to failure. In the process, drainage volume of water from the specimen was recorded using burette while pore water pressure was recorded using U-tube manometer.

The test was repeated with different values of confining pressures (σ_3) of 100, 200, and 300 kN/m². Using the failure stresses corresponding to each value of confining pressure, Mohr's circle was plotted to obtain the shear strength parameters (cohesion, c and the angle of internal friction, ϕ). The shear strength (τ) of the soil specimens was determined using equation (6).

$$\tau = c + \delta_n \tan \phi \quad (6)$$

where δ_n is the normal stress which was determined from Equation 7 and 8

$$\delta_n = \frac{\delta_1 + \delta_3}{2} + \frac{\delta_1 - \delta_3}{2} \cos 2\alpha \quad (7)$$

$$\alpha = 45 + \frac{\phi}{2} \quad (8)$$

4.0 Results and Discussion

The results of the geotechnical investigations are tabulated as follows: The results obtained are discussed based on the engineering properties of soil samples obtained from some of the selected locations in Ado-Ekiti metropolis. In particular the natural moisture content, specific gravity, particle size distribution, Atterberg limits, soil classification, cohesion and angle of internal friction are discussed to assess the geotechnical properties of the soils and their suitability for construction uses. The significance of these parameters is that they affect the behaviour of the soil under load and also are deciding factors in foundation design, pavement construction, stability of embankments and suitability of the soil for construction [1], [2], [18], [19].

4.1 Natural Moisture Content

The moisture content of the soil samples varied from 4.40% to 38.97% which is the moisture content of natural soil. The lowest value was obtained at Basiri 1 and the highest value was obtained at Ado/Ikere Road 3. The wide range of these soil moisture conditions indicates that soils within the study area are not uniformly wet. The differences could be caused by the drainage condition, topography, clay content, particle-size distribution and influence of the parent material [4], [7], [10].

The moisture values derived from this study are wider than those reported by Osuji and Akinwamide [1] for lateritic soils in Ado-Ekiti which ranged from 1.1% to 18.7% moisture content. The higher values obtained in some samples in the present study indicate the higher water retention capability and may reflect the effect of fine soil fractions. Ezenwaka et al [2] also reported high natural moisture content in clayey soils and noted that poor foundation performance can occur in such soils under poor drainage conditions, due to reduced strength.

In fine-grained soils, however, water content is especially significant because it decreases effective stress, reduces inter-particle bonding and decreases shear resistance. This is in agreement with the findings of Olatunde et al. [4] that soils with high activity clay minerals will absorb more water and exhibit poor engineering properties compared to soils with low activity clay minerals. Mitchell [12] and Sridharan and Choudhury [11] also described the effect of clay minerals on swelling, water absorption and strength loss. Thus, it is necessary to carefully evaluate the moisture content of the samples before using them for foundations or pavement layers, especially the samples from Ado-Ikere Road, Abekoko, NTA, Ijigbo and Bank Road.

4.2 Specific Gravity

Specific gravity is in the range from 2.20 to 2.68. These values are in the range typical of lateritic/residual soils. These results are also comparable with those of Osuji and Akinwamide [1] who reported 2.23 to 2.79 for lateritic soils of Ado-Ekiti and Ezenwaka et al. [2] who reported 2.27 to 2.72 for soils investigated in Port Harcourt.

The difference between the specific gravities is due to differences in mineral content, laterization and parent rock influence. Parent rock can affect the engineering index properties of residual lateritic soils [7] and that soils from different crystalline rock types can exhibit varying moisture, plasticity and strength properties [4]. Some samples had higher specific gravity values, which could suggest increased densities of minerals in the pebble and increased enrichment of iron oxides which are common in lateritic soils. Lower values can be due to a higher percentage of lighter minerals or a greater clay influence.

Specific gravity will not directly reflect the shear strength, but is valuable for estimating the mineralogical characteristics of the soil and for calculating other engineering parameters like void ratio, unit weight and degree of saturation. From this observation, it is inferred that soils all over the Ado-Ekiti metropolis are not homogenous and cannot be assumed as one engineering material.

4.3 Particle Size Distribution

The particle size distribution (PSD) results indicate that percentage passing through the 0.075 mm sieve was between 8.20% and 88.06%. This is a representation of a range of soils from sandy lateritic with low fines content to very clayey soils with high fines content. Ado-Ilawe Road 4 and Ado-Ilawe Road 5 had the lowest fines content and Oke-ila 2 had the highest fines content.

This is a wide range, which corroborates the findings of Osuji and Akinwamide [1] which reported that lateritic soils in Ado Ekiti have variable proportions of gravel, sand and fines. Their study also revealed that soils in the area could be categorized in the following engineering groups: Clay of low compressibility, Clay of high compressibility and Silty gravelly sandy soils. The findings presented, therefore, agree with earlier investigations that Ado-Ekiti soils are highly variable, and any geotechnical work requires the soil to be evaluated at a particular location.

Soils of low fines content tend to have good drainage, low compressibility and high frictional resistance. These types of soils are generally more appropriate for pavement layers, fills and foundation support, provided that they satisfy the compaction and strength criteria [6], [18], [20]. Soils with high fines content on the other hand tend to have high water-holding capacity, high plasticity and swell, shrink and settle when moisture content changes [11], [12], [14]. It is important for sites of high fines content like Okela, Abekoko, NTA, Bank Road, and Ijigbo, because this could affect the integrity of the soil under repeated wetting/drying.

Adunoye [16], [17] reported that fines content affects both the cohesion and angle of internal friction of lateritic soils. This corroborates the present findings, which indicated that cohesive behaviour increased with increasing fines content of the sample while frictional resistance decreased. So, the behaviour of shear strength of the soils studied in this research is much affected by particle size distribution.

4.4 Atterberg Limits

The consistency characteristics of the soil samples showed a significant variation from one to the other, as shown by the Atterberg limits. The liquid limit varied between 22.00% and 64.00%, while the plastic limit ranged from 15.00% to 43.56%. Similarly, the plasticity index was found to vary from 5.04% to 32.10% which shows that the soils are low to high in plasticity. Adebayo 2, Abekoko 5 and Ado/Ikere Road 5 are relatively low plasticity index soils that are likely to be more suitable for engineering and construction applications due to their lower compressibility, lower shrink–swell potential and greater volumetric stability. Samples like Bank Road 2, Okela 5, NTA 1, NTA 3 and NTA 4 on the other hand have high plasticity index indicating high clay activity and are more prone to volume changes.

The findings are similar to those of Osuji and Akinwamide [1] who reported the liquid limit, plastic limit and plasticity index of lateritic soil of Ado-Ekiti ranging from 25 to 65, 17 to 43, and 10 to 30 respectively. This similarity implies that the present samples are within the same range of plasticity as is expected for lateritic soils in the metropolis. The plasticity index of 32.10% determined in this investigation, however, indicates that some soils are more plastic and may thus present more of a problem than those reported previously.

Soils with high plasticity tend to contain more clay and are generally more compressible and moisture-sensitive. Ezenwaka *et al.* [2] reported that the soils having high liquid limit and plasticity index had medium to high compressibility and poor engineering properties. Olatunde *et al.* [4] also reported that soils derived from charnockite granites had higher plasticity and low engineering properties than granite derived soils due to the presence of high activity clay minerals. This is in agreement with Mesida [9] who associated the behaviour of engineering soil with the geological and mineralogical conditions of lateritic soil.

From this it is evident that the Atterberg limits have indicated that the engineering performance of the soils in Ado-Ekiti cannot be assessed solely on visual description. Plasticity of soils should be taken into consideration, since it can cause swelling, shrinkage and loss of strength in soils under the influence of moisture changes from one season to another. This is especially so in road subgrades and shallow foundation beds [13], [15].

4.5 Soil classification and soil engineering behaviour

The outcome of the particle size distribution and Atterberg limits tests, the soils are considered to be predominantly lateritic soils with varying amounts of sand, silt and clay. A few samples were sandy silty lateritic soil and the others are more clayey and plastic. This is in line with the classification reported by Osuji and Akinwamide [1] which classified Ado-Ekiti soils as clay of low compressibility to clay of high compressibility and silty gravelly sandy soils as per USCS and AASHTO system.

On an engineering standpoint, the low fines content and the low plasticity of the soils are likely to be better used as subgrade soil, fill soil or foundation soil. Fines-rich soils and/or highly plastic soils will tend to exhibit low permeability or poor drainage, high compressibility and volume change susceptibility. Such soils are suitable for some road and pavement applications, which can be assessed using the Federal Ministry of Works and Housing specifications [6]. BS 1377 [5] is also the basic standard for conducting the laboratory tests required for classification and assessment of soils for civil engineering use. The significance of soil classification is also echoed by Jegede [13] who attributed the failure of pavements in Ado-Ekiti and environs to soil properties, and Adiat *et al.* [15] who suggested that roads failure potential can be better understood by undertaking an integrated geotechnical and geophysical investigation. Therefore, proper classification of Ado-Ekiti soils is necessary for reducing premature pavement failure, differential settlement, and foundation related defects.

4.6 Shear Strength Parameters

The shear strength parameters obtained from the triaxial test show that cohesion ranged from 15.70 kN/m² to 137.90 kN/m², while the angle of internal friction ranged from 4° to 24°. The lowest cohesion value was recorded at Basiri 5, while the highest value was recorded at Ado/Ilawe Road 4. The lowest friction angle values were recorded in some Omisanjana and Ado/Ikere Road samples, while the highest value of 24° was recorded at NTA 4.

These results show that the soils have variable shear strength behaviour. The cohesion values obtained in this study are generally higher than the 5 kN/m² to 87 kN/m² range reported by Osuji and Akinwamide [1] for lateritic soils in Ado-Ekiti. However, the friction angle values are lower than the 16° to 35° range reported in their study. This suggests that many of the soils in the present study derive a greater part of their shear resistance from cohesion rather than from frictional interlocking.

The results also compare well with Iyeke *et al.* [3], who reported cohesion values of 3 kN/m² to 82 kN/m² and friction angle values of 2° to 43° for lateritic soils in parts of Delta State. Their study confirmed that cohesion and angle of internal friction are the two principal parameters used in the Mohr-Coulomb shear strength model. Roy and Dass [21] and Ersoy *et al.* [22] also showed that shear strength parameters can be estimated from soil index properties, while Murthy [23] explained that the slope and intercept of the Mohr-Coulomb failure envelope represent the angle of shearing resistance and cohesion respectively.

The low friction angles recorded in several samples indicate limited frictional resistance and possible high clay influence. This agrees with the findings of Olatunde *et al.* [4], who showed that clay mineralogy affects moisture absorption, plasticity, and strength behaviour. Where soils have high cohesion but low friction angle, their short-term strength may appear satisfactory, but they may still perform poorly under wet conditions or repeated loading. This is because high moisture content and high plasticity can reduce effective stress and weaken the soil structure [11], [12], [18].

Ezenwaka *et al.* [2] similarly found that clayey materials with high moisture content and high plasticity may fail relevant construction specifications despite having measurable cohesion. It should be understood that high cohesion must not be relied upon as the sole criterion to determine suitability of foundations. Also to be considered is the angle of internal friction, plasticity index, fines content, natural moisture content, drainage condition and the anticipated loading condition.

A correlation between index properties and shear strength was developed. The results indicated that the shear strength parameters are significantly affected by the soils' index properties. Generally, the fine content and plasticity of the sample influence the cohesion and friction angle of soil, with high fines content and high plasticity yielding high cohesion and low friction angle while soils with low fines content have greater frictional resistance. This correlation is the same as that reported by Adunoye [16], [17] where the fineness content of lateritic soils affects cohesion and angle of internal friction.

Iyeke *et al.* [3] also showed that plasticity index, specific gravity and percentage passing sieve No. 200 are the input variables that can be used in predicting cohesion and angle of friction of lateritic soil. This indicates that the observed variability is not random but has a relationship with measurable properties of the soils. Although predictive models can help, there are a number of interacting factors that influence shear strength, and laboratory determination is still important, such as soil fabric, moisture condition, mineralogy, density, and stress history [3], [21], [22].

The result also corroborates the results of Olatunde *et al.* [4] who concluded that soils of similar texture could yield different results if their mineralogical composition varies. This is important because Ado-Ekiti is a part of the Basement Complex terrain of Southwestern Nigeria where the residual soils could be from parent rocks of different types. Thus, the engineering properties of the soils must be judged in terms of both index properties and strength properties, not just particle size.

4.7 Implications for Construction Works in Ado-Ekiti

The results have important implications for construction works in Ado-Ekiti metropolis. Soils in the metropolis are not uniform: the wide range of particle size distribution, plasticity, moisture content, cohesion and angle of internal friction demonstrates this. Soil information should not be generalized, or it may result in hazardous or uneconomical design. This is in accordance with Osuji and Akinwamide [1] who pointed out that geotechnical data is important for construction activities in Ado-Ekiti.

Second, the results indicate that soils with high content of fines, high plasticity index, high moisture content, and low friction angle can cause foundation, subgrade and pavement problems. The issues associated with these problems can be differential settlement, drainage issues, reduced strength during wet seasons and lower bearing capacity. Some of the same issues have been noted in investigations of road and foundation failures in Nigeria [13], [15]. Sani *et al.* [24] also pointed out that mineralogical and geotechnical properties of residual soils were also vital in the understanding of the road failure problems.

Thirdly, soil improvement may be necessary in some places prior to the construction. Improvements/remedies that may be considered are compaction control, drainage improvement, replacement of inadequate soil, lime or cement stabilization, and proper foundation depth. Holtz and Kovacs [19], Coduto [18], and Punmia *et al.* [20] emphasized that adequate foundation design, informed by these shear strength parameters, is essential for structural stability.

SAMPLES	Depth (m)	Particle Size Distribution			Atterberg Limits (%)				NMC	USCS	Cohesion ©	Angle of Internal Friction (Φ)
		< 2.00mm (%)	< 0.600mm (%)	< 0.075mm (%)	LL	PL	PI	GS				
ADEBAYO 1	1	90.00	69.94	45.87	33.50	20.86	12.64	2.50	16.99		34.90	22°
ADEBAYO 2	1	91.20	70.67	36.79	22.00	16.96	5.04	2.60	17.53		108.50	10°
ADEBAYO 3	1	99.33	78.08	37.02	30.00	15.41	14.59	2.50	18.01		84.50	15°
ADEBAYO 4	1	98.14	84.20	33.00	36.00	27.31	8.69	2.50	24.52		71.00	15°
ADEBAYO 5	1	95.00	57.75	27.41	44.00	22.58	21.42	2.60	29.31		81.30	17°
BANK ROAD 1	1	50.30	38.85	13.29	56.00	36.70	19.30	2.40	25.21		28.10	12°
BANK ROAD 2	1	89.30	49.20	30.96	59.00	26.90	32.10	2.50	25.28		37.50	17°
BANK ROAD 3	1	85.70	74.00	52.50	30.90	18.20	12.70	2.50	14.51		37.50	11°
BANK ROAD 4	1	89.20	70.22	61.84	46.90	31.50	15.40	2.60	17.29		41.50	8°
BANK ROAD 5	1	94.30	76.33	25.65	40.00	30.83	9.17	2.60	19.73		23.00	19°
ABEKOKO 1	1	80.47	77.87	28.50	26.50	15.00	11.50	2.20	25.55		30.00	9°
ABEKOKO 2	1	84.32	71.07	45.26	36.50	25.98	10.52	2.30	18.37		55.70	5°
ABEKOKO 3	1	99.01	97.56	78.36	41.00	20.90	20.10	2.40	38.37		63.80	4°
ABEKOKO 4	1	99.24	94.42	64.06	44.00	27.00	17.00	2.20	16.97		52.90	7°
ABEKOKO 5	1	98.05	81.15	24.72	50.50	43.56	6.94	2.30	18.01		44.60	8°
OMISANJANA 1	1	70.90	58.80	45.60	35.00	24.23	10.77	2.60	15.70		37.00	9°
OMISANJANA 2	1	75.02	62.84	44.30	53.00	33.40	19.60	2.50	13.86		68.00	4°
OMISANJANA 3	1	97.20	80.24	31.47	51.20	29.80	21.40	2.60	17.24		66.50	4°
OMISANJANA 4	1	98.60	79.34	13.76	36.00	20.53	15.47	2.50	21.94		56.00	6°
OMISANJANA 5	1	80.10	73.97	25.01	42.90	26.91	15.99	2.60	15.75		63.00	4°
ADO/IKERE ROAD 1	1	95.00	73.22	29.33	35.00	26.56	8.44	2.61	26.55		77.80	6°
ADO/IKERE ROAD 2	1	75.80	62.84	44.38	40.00	24.28	15.72	2.35	18.37		77.20	7°
ADO/IKERE ROAD 3	1	60.14	51.13	35.69	34.00	26.37	7.63	2.44	38.97		95.80	4°
ADO/IKERE ROAD 4	1	97.80	85.28	47.03	30.50	21.81	8.69	2.31	16.99		82.80	5°
ADO/IKERE ROAD 5	1	98.30	87.42	42.21	29.20	22.13	7.07	2.57	16.39		80.20	5°
BASIRI 1	1	70.10	55.09	44.03	51.00	34.08	16.92	2.55	4.40		127.40	9°
BASIRI 2	1	69.30	62.79	47.25	50.00	34.08	15.92	2.64	27.43		33.00	18°
BASIRI 3	1	98.33	79.25	35.62	37.50	28.85	8.65	2.61	18.01		32.10	19°
BASIRI 4	1	95.44	77.70	34.75	40.00	25.91	14.09	2.51	24.52		21.40	20°
BASIRI 5	1	98.40	77.63	27.62	46.50	30.91	15.59	2.50	29.31		15.70	23°
OKELA 1	1	89.10	81.20	76.40	55.00	38.81	16.19	2.41	25.21		30.80	11°
OKELA 2	1	91.20	90.28	88.06	52.00	33.07	18.93	2.38	25.38		46.00	9°
OKELA 3	1	73.50	50.40	36.40	52.60	37.13	15.47	2.43	14.51		25.50	11°
OKELA 4	1	80.40	44.00	27.60	40.00	31.27	8.73	2.31	17.29		61.40	8°
OKELA 5	1	60.50	49.60	31.20	64.00	33.24	30.76	2.51	19.73		80.69	13°
IJIGBO 1	1	70.10	54.40	38.00	43.00	26.91	16.09	2.41	17.24		126.50	11°
IJIGBO 2	1	90.42	74.40	48.80	40.90	27.27	13.63	2.47	27.43		78.80	22°
IJIGBO 3	1	87.33	87.40	59.80	46.00	27.28	18.72	2.40	24.98		108.90	11°
IJIGBO 4	1	74.20	69.20	63.20	39.80	25.13	14.67	2.48	23.60		101.90	19°
IJIGBO 5	1	60.30	45.20	32.80	50.00	30.80	19.20	2.67	30.22		46.00	13°
ADO/ILAWE ROAD 1	1	65.30	52.20	35.00	47.90	32.58	15.32	2.68	16.41		131.40	16°

SAMPLES	Depth (m)	Particle Size Distribution			Atterberg Limits (%)				NMC	USCS	Cohesion ©	Angle of Internal Friction (Φ)
		< 2.00mm (%)	< 0.600mm (%)	< 0.075mm (%)	LL	PL	PI	GS				
ADO/ILAWE ROAD 2	1	65.02	50.80	33.60	45.90	31.18	14.72	2.54	13.20		21.40	17°
ADO/ILAWE ROAD 3	1	54.33	34.80	10.40	37.50	26.98	10.52	2.68	18.76		25.60	19°
ADO/ILAWE ROAD 4	1	59.70	35.40	8.20	37.00	21.87	15.13	2.49	22.39		137.90	11°
ADO/ILAWE ROAD 5	1	50.70	35.20	8.20	40.20	22.23	17.97	2.45	16.30		33.30	10°
NTA 1	1	64.30	44.00	22.00	46.00	22.39	23.61	2.53	24.98		55.90	13°
NTA 2	1	84.02	77.60	64.72	42.00	23.40	18.60	2.42	23.40		32.90	21°
NTA 3	1	84.30	77.66	64.72	48.00	22.47	25.53	2.59	30.22		77.20	23°
NTA 4	1	58.13	51.98	46.20	47.00	23.31	23.69	2.46	27.33		61.90	24°
NTA 5	1	90.10	66.96	40.14	29.00	18.50	10.50	2.51	24.73		68.00	23°

Design must be based on sound understanding of soil strength, compressibility, and bearing behaviour. Therefore, construction in locations with low friction angle or high plasticity should not proceed without detailed design checks.

5.0 Conclusion

The shear strength properties of soils in Ado-Ekiti metropolis, Ekiti State, Southwestern Nigeria have been investigated in this study in order to obtain the index properties associated with this.

- The results show that soils are mostly lateritic with different amount of sand, silt and clay contents. The natural moisture content varied from 4.40% to 38.97% and the specific gravity was found to be between 2.20 and 2.68. The liquid limits (LL) of the soils ranged from 22.00% to 64.00%, plastic limits (PL) from 15.00% to 43.56%, and plasticity index (PI) of the soils varied from 5.04% to 32.10%, which showed a high variation in the engineering properties of the soils in the study area.
- The particle size distribution was very variable with fines ranging from 8.20 to 88.06%. This means that some soils are fairly coarse with good drainage, while others are fine-grained, plastic and susceptible to volume change. The Atterberg limits indicated that soils have low to high plasticity. Samples having high plasticity and high fines content may be more compressible and more prone to reduce strength, shrink and swell.
- The shear strength parameters, as well, had a wide range of values. Cohesion varied from 15.70kN/m² to 137.90kN/m² and the angle of internal friction varied from 4° to 24°. Some samples have relatively high cohesion values which suggest clay bonding, and low friction angles with several samples, indicating low frictional resistance, and that it may be moisture sensitive. High cohesion should not, therefore, be used as an indicator of good soil performance.
- The study concludes that not all soils within Ado-Ekiti metropolis are suitable for construction works. Some soils can be used for shallow foundations, pavement subgrades, and earthworks while others may need to be stabilized, improved by drainage, compacted, or detailed design of the foundation before they can be used. The information gained from this study is beneficial to the geotechnical engineers, contractors, planners and other stakeholders in the construction of infrastructure in the metropolis.

6.0. Recommendations

The following recommendations are made based on the results of this study:

- In view of the variations of the properties of the soils in Ado-Ekiti metropolis, it is recommended that before any major construction work in the metropolis, geotechnical investigation of the soil should be carried out at the site.
- Soils that have high fines content, high plasticity, high natural moisture content and low angle of internal friction must not be used directly for foundation or pavement construction without further evaluation.
- In problematic areas, soil improvement techniques, such as compaction control, drainage improvement, lime stabilization, cement stabilization or material replacement should be considered.
- Cohesion should never be used as the only basis for foundation design. Other factors to consider are the angle of internal friction, plasticity index, fines content, moisture condition, and the expected loading condition.

- v. In future, more detailed sampling and analysis of seasonal moisture variation, consolidation testing, and bearing capacity evaluation should be included to assist in the design of the foundations for the metropolis.

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